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Admittance, Isolation, and Radiation Patterns of Rectangular Slot Antennas in the Presence of a Simulated Reentry Sheath

Prepared by G. E. STEWART and K. E. GOLDEN
Plasma Research Laboratory

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Laboratory Operations
THE AEROSPACE CORPORATION

Prepared for SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
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FOREWORD

This report is published by The Aerospace Corporation, El Segundo, California, under Air Force Contract F04701-70-C-0059.

This report, which documents research carried out from July 1969 through January 1970, was submitted 29 July 1970 to Lieutenant Edward M. Williams, Jr., SMTAE, for review and approval.

Approved

R. X. Meyer

R. X. Meyer, Director
Plasma Research Laboratory

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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Project Officer

ABSTRACT

The admittance, isolation, and element radiation patterns of reduced-height rectangular slot antennas in a plasma-clad ground plane have been measured and are compared with theoretical predictions. The plasma sheath simulates the electromagnetic properties of a high-altitude boundary layer and is produced by pulsed electron beam emission from the ground plane in the presence of a low-pressure gas.

CONTENTS

FIGURES

I. INTRODUCTION

The design of antenna systems for operation in the presence of a reentry sheath has long been hampered by the lack of a means of simulating the sheath in the laboratory. For sharp, slender reentry bodies at low altitudes and low signal frequencies, the plasma sheath is thin and collision-dominated. Under these conditions, space cloth can be used for sheath simulation (Ref. 1). At high altitudes, collision frequencies are low, and the boundary layer may be thick enough to produce a significant change in mutual admittance and radiation pattern distortion. In this regime, the boundary-layer plasma can be simulated with a pulsed abnormal glow discharge (Ref. 2). This plasma is produced over a conducting body by insulated electrodes inserted into the surface and excited at a 500-Hz repetition rate with kilovolt pulses. Although this technique is applicable to a variety of shapes, initial work has been focused on measurements for rectangular slots on a plasma-clad ground plane. Theoretical prediction techniques exist for admittance, isolation, and radiation patterns for this configuration (Refs. 3 - 5).

II. EVACUABLE MICROWAVE ANECHOIC CHAMBER

To produce the plasma layer, it is necessary to provide a low-pressure environment of 0.1 to 0.5 Torr of argon. Since the linear interaction of high-frequency electromagnetic waves with a cold plasma depends only on the electron density distribution and the collision frequency, it is immaterial whether the neutral gas is air or argon. The discharge used requires no confining walls but only a low-pressure gas environment. In order to realize the full potential of this simulation technique, we constructed a conical evacuable microwave anechoic chamber. With absorber in place, the tank can be evacuated to <1 mTorr and has an X-band reflectivity of -50 dB. The chamber and microwave recording equipment are shown in Fig. 1. In Fig. 2, a plasma-clad ground plane with a pair of rectangular slots is shown in the chamber. The ground plane is extended beyond the plasma layer to minimize edge scattering.

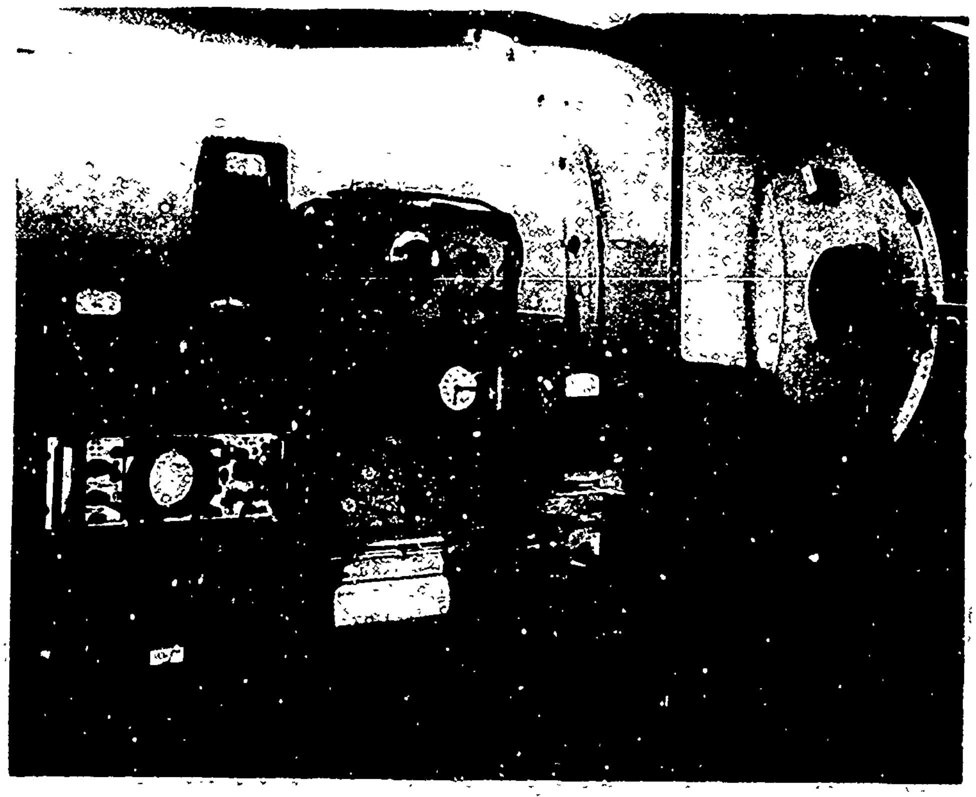

Figure 1. Evacuable Microwave Anechoic Chamber and Associated Microwave Equipment

Figure 2. Plasma-Clad Ground Plane with Rectangular Slots in Anechoic Chamber

III. ADMITTANCE, ISOLATION, AND PATTERN CALCULATIONS

The plasma layer produced over the ground plane is uniform across the surface but varies in a direction normal to the surface. The shape of the electron density profile at 0.4 Torr of argon is shown in Fig. 3(a), as determined from the ion saturation current measured by Langmuir probes at 10 μsec after the termination of the ionization pulse. The peak electron density was determined by matching the measured and the calculated broadside attenuations for constant aperture voltage [Fig. 3(b)]. Computations were performed assuming that the electron density profile of Fig. 3(a) was approximated by a large number of homogeneous slabs using the analyses of Refs. 4 and 5. Because of the low collision frequency, 1000 slabs were necessary to approximate the plasma layer.

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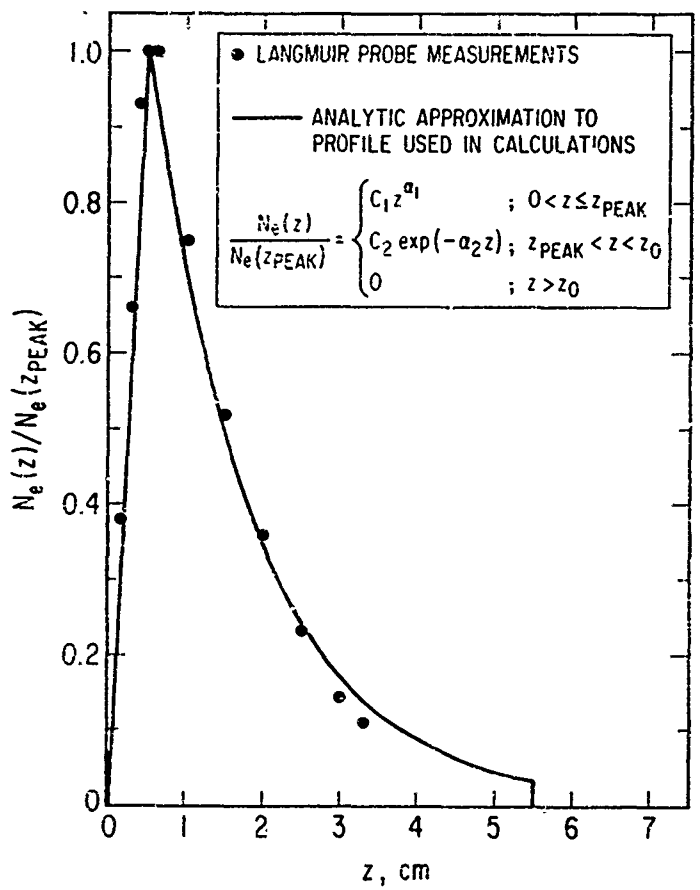

Figure 3(a). Normalized Electron Density Profile

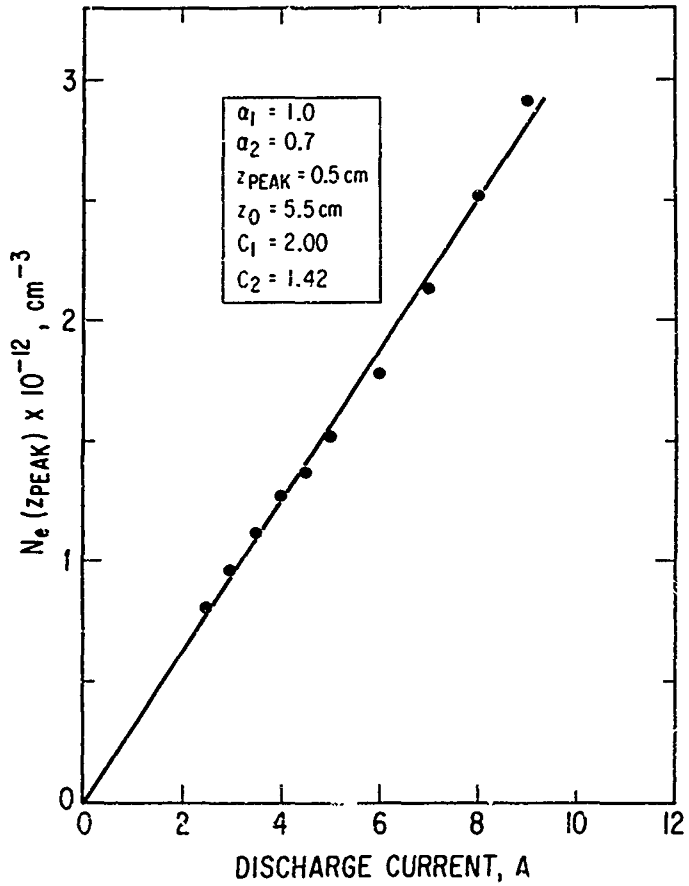

Figure 3(b). Peak Electron Density as a Function of Discharge Current

IV. EXPERIMENTAL RESULTS

The measured radiation patterns are compared with the theoretical computations in Fig. 4. The measurements were obtained by holding the aperture voltage constant to correspond to the radiation pattern calculations.

Self-admittance and isolation were measured with the discharge in an evacuable antenna cap to minimize the effects of the waveguide separating the slots from the microwave bridge used for the admittance and isolation measurements. The self-admittance is shown on a Smith chart in Fig. 5 with the slot configuration shown in the inset. The measurements are plotted as a function of discharge current, and the calculations are plotted as a function of peak electron density. The change in E-plane isolation and broadside signal attenuations are displayed in Fig. 6 for the conditions of constant incident power.

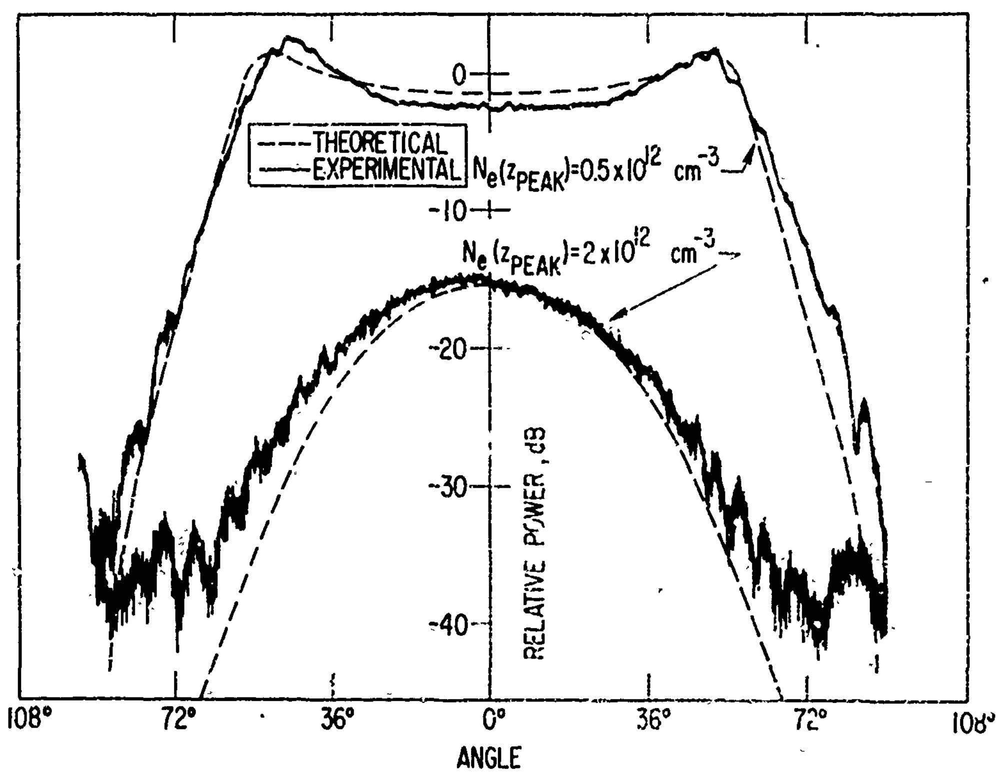

Figure 4. Measured and Calculated Radiation Patterns

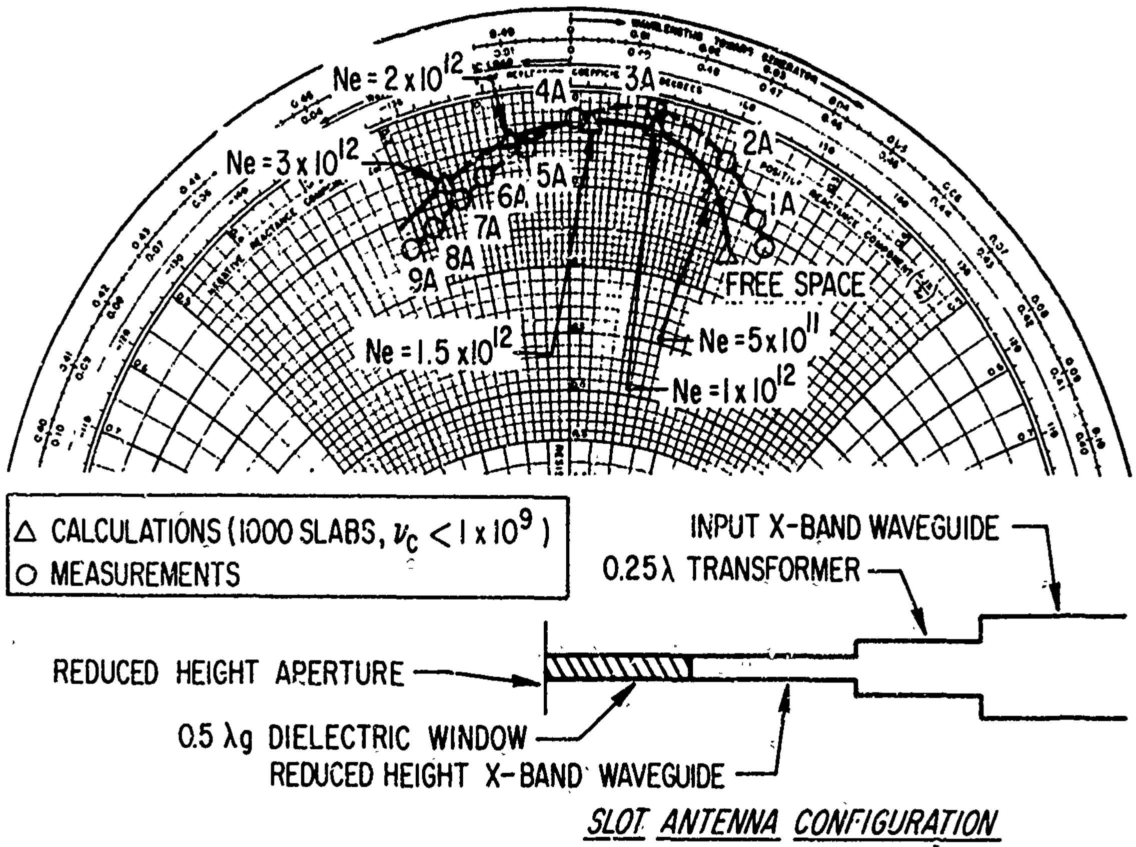

Figure 5. Measured and Calculated Aperture Admittance

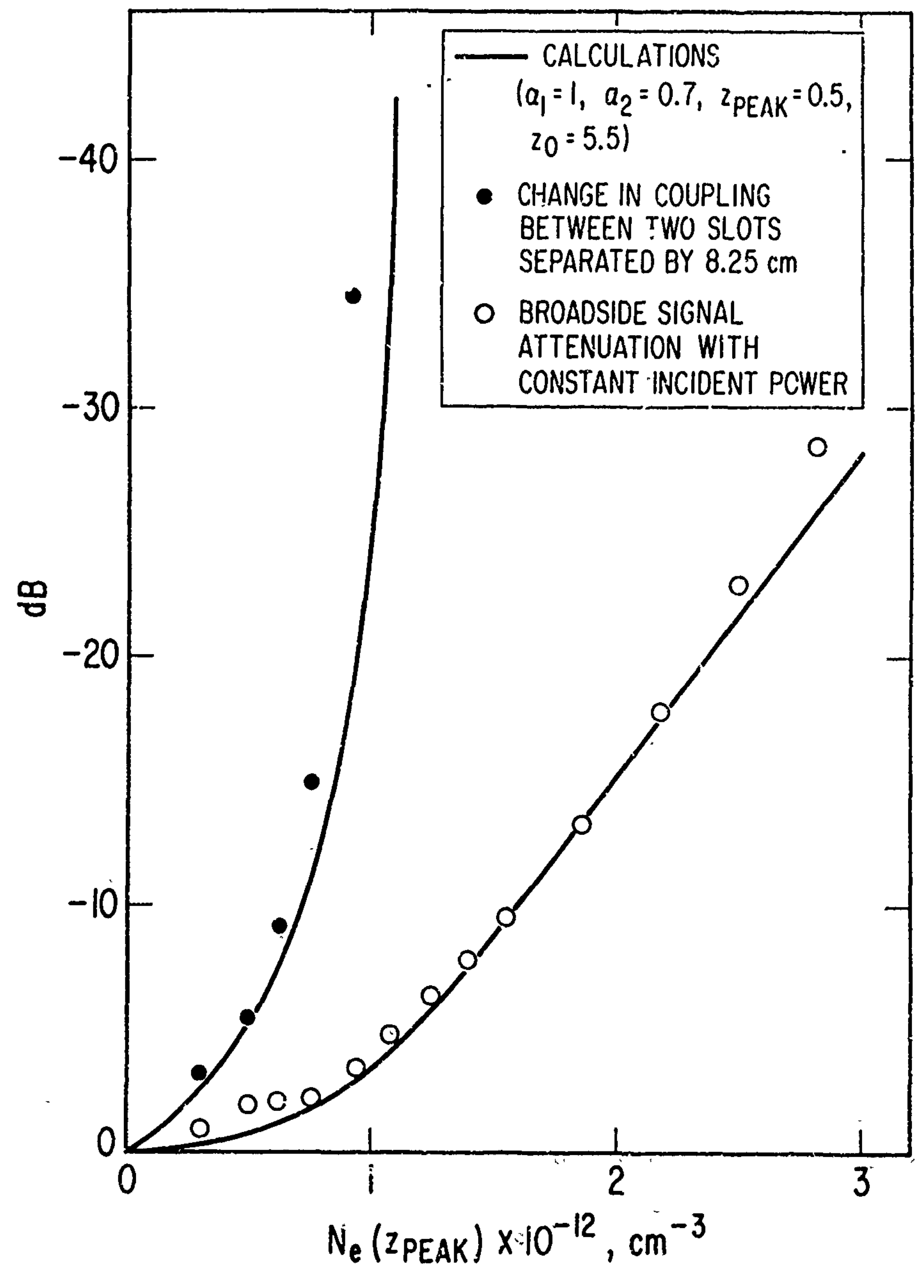

Figure 6. Increase in Slot Antenna Isolation and Broadside Signal Attenuation as a Function of Electron Density

V. CONCLUSIONS

The admittance, isolation, and radiation patterns of reduced-height rectangular slot antennas in the presence of an inhomogeneous plasma layer have been measured and compared with calculations based on the equivalent dielectric constant for a cold plasma. Theory and experiment are in good quantitative agreement since there are none of the scattering problems encountered when discharges are confined by glass walls.

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